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CORROSION RESISTANCE OF IRON AND STEEL

The Letter Circulars are designed to answer specific inquiries and at the same time to obviate the necessity for preparation of a large number of letters on the same subject. There is no guarantee that the information given in the Letter Circulars is correct except as of the date of issue. Material of a permanent value appears in the printed publications of the Bureau.

Letter Circulars are not available in the Government Printing Office, and the supply at the Bureau of Standards is limited.

Many inquiries are received by this Bureau in regard to the resistance to corrosion of cast iron, and of steel, wrought iron, commercially pure open-hearth iron and copper-bearing iron or steel in sheet, pipe, wire and other forms both bare and zinc coated or otherwise "rust proofed".

Some inquirers request opinions on the suitability of specific makes or brands of these materials for specific uses.

It is not the policy of the Bureau to recommend or decry specific makes or brands of any article. Its tests and investigations deal with types of material, not with the merits or demerits of a particular maker's product. This Letter Circular is prepared to put those making such inquiries on types of material in touch with published data and opinions on the subject.

There are many papers in scientific and technical periodicals on this subject, dealing with the performance of these materials in different types of service. Most of the papers have naturally been written by men on the technical staff of various producers of the materials.

Instances of good or even phenomenal life for many types of material are on record, but since, in general, only one type of material was used in the particular service reported on, the question as to what life competing materials would have given under identical service conditions is unanswered.

Another class of papers are those, again more often written by the technicians of the producers than by users, which report accelerated laboratory tests of various competing materials. The actual data reported are in general presumably accurate. The interpretation thereof is often subject to discussion, sometimes acrimonious, by those whose experience or whose laboratory experiments lead to different conclusions. Some of this criticism is often quite just. For example, two materials completely submerged in an acid may show relative rates of corrosion such that material A is obviously more resistant than material B. But it does not follow that on exposure to salt air, for instance, material A is superior to material B. The correlation of accelerated laboratory tests of different kinds with comparative service tests carried out under identical conditions is very desirable but no conclusive correlation of such a nature has yet been made, and such tests as are in progress must go on for years before the comparative service tests are completed so that valid conclusions may be drawn therefrom.

A third class of papers or reports are those by impartial observers, such as users of the products under discussion or by technical societies whose committees are made up of both users and producers, and among the latter, those interested in the manufacture of the various competing types of material.

Among the accounts of presumably impartial and comprehensive tests is one of work done at the German Materialprufungsamt and reported by Bauer (Mitt. Mat. 38, 1920, p. 85, Stahl u. Eisen 41, 1921, pp. 37, 76). Exposure tests, lasting 4 to 4-1/2 years were made in a relatively pure atmosphere at the laboratory, in one comtaminated by industrial smoke at a steel works, and in salt air, of several series of steels in large sheets, not freed from scale, averaging about 0.08% C, 0.45% Mn, 0.10% Ni and varying in copper content from 0.10% to 0.40%. No copper-free material was tested. Other large sheets were immersed in sea-water for 14 months, and still others were buried in the ground for 5 years at the same three locations as were chosen for atmospheric tests.

Other exposure tests and many laboratory tests in various corroding media were made on smaller specimens of the materials, freed from scale. Bauer states that in the industrial atmosphere of the steel works, where sulphurous or sulphuric acid was doubtless present, the copper-rich sheets were decidedly less attacked than those lower in copper. Under all the other conditions of exposure or test Bauer was unable to find any consistent differences in behavior that would warrant his accepting the idea that a variation in copper content from 0.10% to 0.40% had any clear effect upon the life of the sheets.

While these German government tests covered quite a range of conditions and quite a period of time, they were not as exhaustive nor as long continued as some American tests, nor did they include several types of iron and steel much used in the United States.

The American Society for Testing Materials through its Committee A-5 has conducted a series of exposure tests at Pittsburgh, Annapolis and Fort Sheridan, Ill., upon bare (un-galvanized) sheets of different gages together with some corrosion tests in Washington, D. C. city water constantly renewed; in acid mine water of the Pittsburgh district, and in brackish water in the Severn River at Annapolis. Both the atmospheric and the underwater tests were made on various ferrous materials, such as wrought iron, commercially pure open-hearth iron, open hearth steel, Bessemer steel etc. low in copper and similar materials with 0.15 to 0.50% copper.

The results of the inspection of these tests are given in detail, by tables and photographs, in the Proceedings of the American Society for Testing Materials from 1918 on, (which can be consulted at many public libraries or purchased from the Secretary of the Society, 1315 Spruce St., Philadelphia).

In general, tha attitude of the committee has been to present the data in progress reports and require the reader to draw his own conclusions. A few tentative conclusions have, however, been drawn. In a report of the sub-committee on inspection, unanimously approved by the sub-committee (Proc. A. S. T. M., Vol. 22, Part 1, 1922, p. 170) it is stated "This information continues to bear out the conclusions of the 1921 report that copper-bearing metal in the Pittsburgh location shows marked superiority in rust-resisting properties as compared to non-copper bearing material of the same general composition". This applies to bare, un-galvanized sheets exposed in the air.

In reference to tests of similar materials immersed in tap, brackish, or mine water, the committee states (Proc. A.S. T.M. Vol. 24, Part 1, 1924, p. 220), "The tests thus far do not indicate any outstanding superiority for any one type of metal, and the presence of copper added to the various types of metal does not increase its resistance to corrosion, when the samples are totally and continually submerged in running water of acid or alkaline reaction[1].

Results of the most recent inspection, which will be summarized in the 1926 report of Committee A-5, suggest a very slight difference in favor of the copper-bearing material in some of the under-water tests. The conclusion drawn by many impartial observers of previous under-water tests has been to the effect that if any difference was detectable, it was in the direction of slightly poorer service under-water from the copper-bearing material. Before final conclusions can be drawn the A. S. T. M. tests will have to be carried to completion.

That final conclusions have not yet been drawn by the A. S. T. M. or by government departments is evidenced by A. S. T. M. Tentative Specifications for hot-dipped galvanized sheets A93-24T (Proc. A. S. T. M. Vol. 24, Pt. 1, 1924, p. 775) and by Standard Specifications for (zinc-coated) corrugated metal pipe culverts (American Association of State Highway Officials and Department of Agriculture) U. S. Department of Agriculture Circular 331, November, 1925, both of which allow the purchase of either copper-bearing or non-copper bearing material.

Since the tests mentioned above are all on bare, ungalvanized material, which is less commonly used in service where corrosion is to be resisted, than is material galvanized or zinc-coated by various methods, it is not yet known by impartial tests what the performance of the various base materials covered with a zinc coating will be. Since the nature of the initial coat of rust or corrosion products that forms upon a piece of iron or steel may affect the progress of the rusting or corrosion it is conceivable that the initial coat may not be similar to that formed on the uncoated sheets used in the atmospheric and submerged corrosion tests.

However, this Committee (A-5) of the American Society for Testing Materials has in progress another comprehensive series of exposure tests on zinc-coated materials with different weights of coating on different base materials, in form of sheets, wire, fencing, etc., coated by different processes.

Exposure tests are to be made at five different locations. Accelerated laboratory tests will be made, for comparison with the exposure tests when the latter are completed. Details of the test program appear in the 1925 Proceedings of the A. S. T. M. Part 1, p. 105.

It is not to be expected that conclusive results of these tests will be obtained for many years. The tests of uncoated material have gone on since about January 1, 1917 and are still incomplete. On account of the much longer life of zinc-coated materials, which will be very marked in the case of the heavier coatings, it is unlikely that even tentative conclusions can be drawn within ten years.

It is rather well-established that within the limit set by the cracking or flaking of the coating on material that has to be formed after galvanizing or zinc-coating, the life of the coating is, broadly, the greater the heavier the zinc coating. The effect of differences in technique or method of zinc coating and of the composition or purity of the coating will in general be secondary to the main factor of the thickness of the coating. It is obvious also that for any given composition, the thicker the sheet, wire, etc. (i.e., the heavier the gage) the longer the life will be. Coating a fabricated article such as garbage cans or wire fencing after fabrication allows the use of a heavier coating than would resist cracking during fabrication and, if heavier coatings are actually used, coating after fabrication is generally believed to produce a superior article.

The Bureau of Standards is cooperating with the A. S. T. M. in the tests on bare and on coated iron and steel and has not completed nor has it under way, separate exposure or service tests in these fields.

The corrosion of pipe in soils is, however, the subject of a separate investigation which has been under way at the Bureau of Standards since 1922. A preliminary report was presented before the American Foundrymen's Association in 1924, (Logan, K. H., Soil Corrosion Investigation, Trans. A. F. A. Vol. 32, 1925, p. 144). Specimens are dug up and inspected every two years. The preliminary report states "In so far as the conclusion may be warranted from short time tests, the results indicate that no one of the commonly used pipe materials tested is generally superior to the others under all soil conditions. On the other hand, the tests seem to show that the pipe material best suited to one soil condition may give a relatively poor showing under a different soil condition".

These tests include wrought iron, commercially pure open-hearth iron, cast iron, open hearth steel,bessemer steel and copper-bearing steel as well as a large number of other materials and various coated specimens. The second inspection is being made in 1926 and a further progress report will be made when the inspection is complete and the results tabulated.

Few comprehensive reports of tests by experimenters unconnected with producers are known in the field of corrosion of water pipes or of culverts, though various producers have made or have under way tests in these important fields.

The U. S. Department of Agriculture, Bureau of Public Roads, installed a few bare and galvanized culverts of bessemer, open-hearth, and copper-bearing steels and of copper bearing iron and ingot iron in Texas in 1915, and reported in its Bulletin 586, February 28, 1918, (which is out of print) on an inspection made after about two years of service. The galvanized culverts were then all in "apparently new condition". The bare culverts were showing some attack but no clear differentiation among the various materials was shown. The Bureau of Public Roads stated in March, 1926 that some difference in condition had recently begun to be shown, and that another inspection is to be made soon, after which, if any worth-while conclusions can be drawn, the results will be promptly published.

The National Research Council, Highway Research Board (Mr. R. W. Crum, Ames, Iowa, Chairman Culvert Committee), is studying the culvert problem but has as yet published no report.

The California Highway Commission, Sacramento, California, has examined some 5000 culverts and is now correlating the information obtained. This will not be completed before June, 1926, at the earliest, and no decision has yet been made as to whether the results will be published.

The Wisconsin Highway Commission, Madison, Wisconsin, is now engaged in a comprehensive field survey of culvert life. Two thousand culverts were inspected, in 1925, but before the work is completed so as to justify giving out information, it is expected that eight thousand will be inspected.

The Sub-Committee, on Corrugated Metal Culverts for Railway Purposes, of the American Railway Engineering Association, states - (Bulletin A. R. E. A. 27, No. 284, Jan. 1926, p.794) "The Sub-committee has no report to make at this time on the question of relative durability".

The conditions of service vary so greatly that it is, so far, impossible accurately to predict the life of any ferrous material in any given service. It is generally equally impossible accurately to predict the relative performance of two different types of material in the same service unless these materials have already been subjected to impartial comparative test under the identical conditions of service.

A common error in the consideration of corrosion tests is to assume that satisfactory or unsatisfactory performance under one set of conditions means that performance will be similar under another set of conditions. The relative standing of different materials is very often altered as the conditions are altered.

For information of practical value, primary dependence must be placed on such experiments as the several A. S. T. M. series of tests and as the culvert inspections under way in various states, in all of which much time must still pass before completion. Isolated service records in which but one material was used only indicate tendencies. Proof of superiority in service requires that the different materials shall have been used under same conditions. Laboratory tests lasting days or months may sometimes be as valuable as service records of years because the variables involved are under control, but many laboratory tests, in the attempt to secure information rapidly, exaggerate the conditions of corrosion and may so alter the conditions as to give misinformation rather than information.

Until direct correlation is shown between a given accelerated test and a given service the accelerated test is chiefly valuable for what it indicates rather than what it might at first sight appear to prove. Accelerated tests which do have direct correlation are badly needed and much work is being done to find such tests. Some accelerated tests certainly give useful information, whether or not they correlate exactly with service results. To date, however, much of the corrosion data in the literature, whether based on laboratory tests or service records, has to be read with the realization that under conditions other than those to which the data refer, different results might be obtained.

Nevertheless the opinions and information published on the performance of various classes of material in service or in laboratory tests may be of use, and a selected bibliography of about 300 titles in scientific and technical literature is appended. No attempt is made to cover the voluminous literature of corrosion in general, although reference is made to a few books, bibliographies and general articles which will serve as introduction to a study of the general corrosion problem. The aid of the metallurgical departments of representative producers of the various types of ferrous products has been enlisted in the preparation of the bibliography, in order to avoid the omission of important articles recording tests especially favorable or unfavorable to any particular type of product.

It should be pointed out that while iron or steel protected by suitable coatings such as paint, renewed as needed, or by a heavy coating of zinc or cadmium may often, in normal uses and normal locations, be the cheapest in respect to cost vs. life, yet they are inherently corrodible. When corrosive conditions are severe it is often good economy to select a more expensive material which is inherently resistant to that type of corrosion in question and which need not depend so completely on protective coatings for long life.

While small additions of other elements such as copper, molybdenum, etc., may slightly reduce the rate of corrosion of iron or steel, to secure anything approaching complete resistance under severe conditions either ferrous alloys of entirely different types from ordinary iron or steel, or non-ferrous alloys, are generally required. Iron or steel with approximately 14% silicon, or 13% chromium or 30% nickel, has an entirely different order of resistance to corrosion than have the common iron and steel products. Aluminum and its alloys, copper, brass, bronze, lead, nickel and its alloys, tin and zinc, beside the noble metals, all show corrosion-resistance of very high order under appropriate conditions.

Each of the metals and alloys is well able to resist corrosion under some conditions and poorly able to resist it under others. To defeat corrosion one must adapt the materials to the conditions of service or alter the conditions to meet the requirements of the material.

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